SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
400 COMMONWEALTH DRIVE WARRENDALE, PA 15096

SAE Technical Paper Series

891490

Potential for Reduction of Decompression Sickness By Prebreathing With 100% Oxygen While Exercising

James T. Webb
KRUG International
San Antonio, TX

Gene A. Dixon
US AF School of Aerospace Medicine
Brooks AFB, TX

Janet F. Wiegman
KRUG International
San Antonio, TX

19th Intersociety Conference on Environmental Systems
San Diego, California
July 24-26, 1989

Accesion For	
NTIS CRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

All SAE papers are abstracted and indexed in the SAE Global Mobility Database

SAE GLOBAL MOBILITY DATABASE

ISSN 0148 - 7191

Printed in U.S.A.

891490

Potential for Reduction of Decompression Sickness By Prebreathing With 100% Oxygen While Exercising

James T. Webb
KRUG International
San Antonio, TX
Gene A. Dixon
USAF School of Aerospace Medicine
Brooks AFB, TX
Janet F. Wiegman
KRUG International
San Antonio, TX

ABSTRACT

Exercise performed for at least 30 min while prebreathing 100% oxygen prior to decompression has been reported to increase efficiency of denitrogenation by 100-500%. The incidence of decompression sickness following such a prebreathe was decreased by 50% compared to resting prebreathe. If prebreathing with exercise is to have an operational application, it must be brief, it must significantly reduce standard prebreathing times, it must not create excess fatigue, and it must use exercise equipment compatible with aerospace operations. This article provides background and recommends parameters for a test to determine the operational feasibility of prebreathing with exercise.

DENITROGENATION PRIOR TO DECOMPRESSION by prebreathing with 100% oxygen has been studied extensively and found to be an effective means of reducing or eliminating the incidence of decompression sickness (DCS) (3,6,12,15,23, 26). Prebreathing for up to four hours to avoid or reduce the incidence of DCS is an essential and standard operational procedure before exposure to low pressures during extravehicular activity (EVA) and to protect against DCS should inadvertent decompression occur during high-altitude reconnaissance flights. Time-consuming DCS preventive measures interfere with efficient utilization of the crew's time by reducing the productive portion of their fixed-length work day and delaying the start-time of their efforts. The optimal solution would be the development of pressure suits to satisfy the requirements of mobility, comfort, and function while, at the same time, maintaining a sufficient pressure differential to avoid the possibility of DCS. Until such suits become available for both high-altitude and space operations, other alternatives must be investigated.

If the efficiency of the denitrogenation process could be enhanced, the time spent prebreathing could be reduced. Experimental evidence showing substantial reduction in prebreathing time, with no increase in incidence of DCS, would provide justification for a change in operational decompression procedures. However, prebreathing time would have to be reduced enough that crewmembers could prebreathe as little as 15 min. They would then don a pressure suit and immediately depart for the aircraft to complete normal operations before takeoff while continuing to prebreathe in the sealed pressure suit. The prebreathe normally accomplished prior to takeoff for high altitude reconnaissance missions that includes donning a pressure suit prior to prebreathe, would thus be significantly shortened, providing an operational savings of time.

If the current 3-4 h prebreathing time prior to EVA could be significantly shortened by an enhanced denitrogenation procedure, considerable enhancement of mission effectiveness would result. A reduced prebreathing time would also allow safer and more timely response of astronauts to emergency situations requiring EVA.

BACKGROUND

Increasing the time of prebreathing, hence increasing the elimination of nitrogen from the body, has been shown to decrease the incidence of DCS (12,15,21,23). The rate of nitrogen exchange between the body and the breathing environment has long been recognized as being directly dependent upon the rate of blood flow and the solubility of nitrogen per unit mass of tissue (11). Later work supported this concept with reports indicating that the rate of denitrogenation is a specific function of cardiac output and blood-tissue perfusion rate (3,4,18,19).

0148-7292/89/0724-1490$02.50

Since skeletal muscle accounts for about 40% of the body, a large increase in blood flow to skeletal muscle enhances the rate of muscle denitrogenation. Strenuous exercise can increase blood flow to skeletal muscle by more than 20-fold by stimulating cardiac output and opening muscle capillaries. Therefore, it follows that one possible means of increasing efficiency of denitrogenation and thereby reducing DCS is to increase the cardiac output and blood-tissue perfusion rate by exercising while prebreathing. Indeed, a large majority of previous reports have indicated that exercise performed while prebreathing 100% oxygen prior to decompression increased the efficiency of denitrogenation (1,5,10,24) and decreased the incidence of DCS (1,24).

A problem may exist due to the possible formation of bubbles by cavitation during exercise prior to decompression. These bubbles could conceivably enlarge during decompression and increase DCS symptoms. However, the concern of bubble formation appears to be unwarranted. Harvey et al. (17) reported that air and nuclei fail to pass the pulmonary capillaries, thus documenting a mechanism for disposal of any bubbles formed during exercise prior to decompression. In addition, Balke (1) found that mild to severe exercise performed by 6 subjects breathing ambient air did not significantly increase the susceptibility for DCS during ascents to 38,000 ft (11,582 m) 10 min after the exercise.

Bigelow et al. (8) used several physiologic parameters of exercise in developing their mathematical models of DCS. They reasoned that exercise: 1) raises body temperature; 2) increases cardiac output; 3) alters the respiratory quotient; and 4) changes the rate of oxygen consumption. An increase in body temperature was studied by Balldin (2), who found that indeed an increase in environmental temperature elevated nitrogen elimination. Since exercise also produces heat, muscle peripheral vasodilation occurs to dissipate heat, provide additional oxygen and reduce buildup of carbon dioxide. A concurrent increase in blood flow to subcutaneous layers of fat tissue has also been suggested (2).

Balke (1) found that 7 subjects breathing 100% oxygen, eliminated an average of 640 cc of nitrogen in 60 min of rest which increased 146% with mild exercise. However, his (1) decompression experiments showed a less dramatic improvement in tolerance to DCS, leading him to conclude that exercise was only mildly effective. His exercise level was about 8.75 ml oxygen/ kg.min, which approximates only 2.5 times resting oxygen consumption (9). This level is probably too low to cause sufficient changes in cardiac output, circulation, and ventilation rate necessary to enhance denitrogenation enough to affect DCS. Earlier researchers, also using low levels of exercise, reported similar results; a significant enhancement in denitrogenation (5,14) and either a reduction in DCS (14) or no effect on incidence of DCS (16). Since the exercise types, exercise levels, prebreathing times, and severity of exposures used in these studies have varied so much, specific comparisons are unwarranted (13).

The exercise levels in the article by Webb et al. (24) were much greater than those described by other authors. The subjects "either jogged in place for the entire half-hour, or else sprinted vigorously in place as frequently as possible during the half-hour." We estimate this level of exercise to be well over 60% of maximal oxygen uptake. They found that one h of prebreathing with this level of exercise during the first half hour significantly reduced rates of limb bends (Type I DCS) (24). However, this level and duration of strenuous exercise may be too fatiguing while prebreathing, and their equipment limitations due to a high ventilation rate reduced operational practicability.

PROPOSED STUDY

We believe that the definitive experiments have not been conducted in developing the operational use of exercise while prebreathing 100% oxygen. Therefore, we plan to conduct research based on a short prebreathing time as determined by the requirements of high-altitude and space operations. We plan to accomplish this goal with exercises that include the upper body and use improved breathing and exercise equipment.

These exercises should produce almost 100% denitrogenation in the faster tissues within about 15 min. Rapid denitrogenation of the faster tissues will enhance more rapid release of nitrogen from adjacent slower tissues due to the favorable diffusion gradient. A residual effect of this short, intense period of exercise is enhanced denitrogenation for at least 30 min after the exercise is completed due to continued increases in ventilation and tissue-blood perfusion rate. Thus, the period of time between completing the strenuous exercise and completing ascent to operational altitudes would provide additional denitrogenation to reduce the DCS incidence.

We propose the level of exercise during prebreathe to be at least 70% of each subject's maximal oxygen uptake. This level is supported by the research of MacDonald and Pilmanis (20) who found that at "approximately 60% of the maximal oxygen uptake and greater, the ventilatory drive was sufficient to increase ventilation and reduce alveolar carbon dioxide pressure" to below 50 mmHg. Our study, using a 10-15 min period of prebreathing while exercising, would reduce the fatigue level observed during an earlier study (24), shorten recovery times, and reduce prebreathing time to meet operational requirements.

We will use exercise equipment during the prebreathe period that is compatible with aerospace operations. Since these exercises will be performed in space, they must be able to be performed in a weightless environment. We will incorporate individual levels of fitness, stature, and strength to ensure that consistent levels of exercise are used for each subject. Our exercise equipment will be credible as a research tool that will measure work load and level of effort. We will also consider the availability of space for the exercise equipment in the operational environment.

We plan to use exercise equipment such as an arm and leg cycle ergometer or Versa-Climber to provide the necessary balance and intensity of upper and lower body exercise (7). Determination of blood lactate levels before, immediately after, and up to 5 min post-exercise will be accomplished to establish an objective measure of the level of exercise attained by each subject.

Testing the influence of the selected exercise on the incidence of DCS will be accomplished at a hypobaric chamber pressure of operational significance to high-altitude and space missions. The study will have two control exposures with standard 100% oxygen prebreathe at rest for: a) 1 h and b) a shortened prebreathe period equivalent to the prebreathe period with exercise. Nitrogen elimination during prebreathing periods will be quantified using a mass spectrometer. Bubble detection using Doppler ultrasound (22) will be used to provide additional indications of prebreathing effectiveness.

Crewmembers exposed to decompression during normal operations continue to perform tasks which require mental and physical work. Since these activities are distractions which may delay recognition of DCS symptoms, our subjects will be required to perform types of exercises and have mental distractions during their decompression exposures to closely simulate the operational environment. Exercises performed in our previous efforts (25), while watching action-oriented videos, will be used in these studies. Since crewmembers are not queried regularly by controllers as to their physical well-being, our subjects will be treated in a similar manner.

In summary, previous studies limited the operational practicability of exercise-enhanced denitrogenation to reduce DCS by using extended prebreathing times and intensities of exercise which did not achieve acceptable results. Our study will use the parameters discussed in this article to test the efficacy of short-term, strenuous exercise while prebreathing 100% oxygen to significantly reduce DCS during exposure to low environmental pressures.

ACKNOWLEDGEMENT

This researach was sponsored by the USAF School of Aerospace Medicine, Brooks AFB, TX, in part by USAF Contract F33615-85-C-4503 and USAF Contract F33615-89-C-0603.

REFERENCES

1. Balke B. Rate of gaseous nitrogen elimination during rest and work in relation to the occurrence of decompression sickness at high altitude. USAFSAM, Randolph Field, TX, Project #21-1201-0014, Report #6. 1954;6pp.

2. Balldin UI. Effects of ambient temperature and body position on tissue nitrogen elimination in man. Aerospace Med. 1973;44:365-70.

3. Bateman JB. Susceptibility to decompression sickness: The effects of prolonged inhalation of certain nitrogen-oxygen mixtures compared with those of exposure to pure oxygen. Comm. Aviat. Med. Report #364. 1944;23pp.

4. Behnke AR, Thompson RM, Shaw LA. The rate of elimination of dissolved nitrogen in man in relation to the fat and water content of the body. Am J. Physiol. 1935;114:137-46.

5. Behnke AR, Willmon TL. Gaseous nitrogen and helium elimination from the body during rest and exercise. Am. J. Physiol. 1941;131:619-26.

6. Behnke AR, Welham W, Yarbrough OD. The value of preliminary oxygen inhalation for the prevention of decompression sickness during high altitude flight. Comm. Aviat. Med. Report #114. 1942;8pp.

7. Bergh U, Kanstrup I-L, Ekblom B. Maximal oxygen uptake during exercise with various combinations of arm and leg work. J. Appl. Physiol. 41:191-196.

8. Bigelow JH, DeHaven JC, Shapley ML. Altitude bends in humans: An investigation using mathematical models and a computer. Rand Report R-1002- PR. 1972;99pp.

9. Blair SN (Chair). Guidelines for exercise testing and prescription as set forth by the American College of Sports Medicine, 3rd Ed. Lea & Febiger. 1986.

10. Boothby WM, Luft UC, Benson OO. Gaseous nitrogen elimination. Experiments when breathing oxygen at rest and at work, with

comments on dysbarism. Air University Project Number 21-53-003, Report #1. 1951;33pp.

11. Boycott AE, Damant GCC, Haldane JS. The prevention of compressed-air illness. J. Hyg. London. 1908;8:342-443.

12. Clarke RW, Humm FD, Nims LF. The efficacy of preflight denitrogenation in the prevention of decompression sickness. Comm. Aviat. Med. Report #472. 1945; 12pp.

13. Cook SF. Environmental factors affecting decompression sickness. Part II. Role of exercise, temperature, drugs and water balance in decompression sickness. In: Fulton JF (ed) Decompression Sickness. Saunders, Philadelphia. 1951;223-41.

14. Evelyn K. The effects of low barometric pressure on the health of the adult male in the age group 19-32. Comm. Aviat. Med. Report #19. 1941;52pp.

15. Ferris EB, Webb JP, Ryder HW, Engel GL, Romano J, Blankenhorn MA. The protective value of preflight oxygen inhalation at rest against decompression sickness. Comm. Aviat. Med. Report #132. 1943b;8pp.

16. Gray JS. The prevention of aeroembolism by denitrogenation procedures. SAM Report, Project #101 and Comm. Aviat. Med. Report #123. 1942;7pp.

17. Harvey EN, Whiteley AH, McElroy WD, Pease DC, Barnes DK. Bubble formation in animals II. Gas nuclei and their distribution in blood and tissues. J. Cell. Comp. Physiol. 1944;24:23-34.

18. Henry FM. Effects of exercise and altitude on the growth and decay of aviator's bends. J. Aviat. Med. 1956;27:250-9.

19. Lawrence JH, Jones HB, Berg WE, Henry FM, Ivy RC. Studies on Gas Exchange. Memorandum Report MCREXD-696-114 1948;224pp.

20. MacDonald JW, Pilmanis AA. Carbon dioxide retention with underwater work in the open ocean. In: Underwater Physiology VII. Bachrach AJ, Malzen MM (eds). Undersea Medical Society, Bethesda, MD. 1981;197-207.

21. Maio DA, Allen TH, Bancroft RW. Decompression sickness in simulated Apollo pace-cabin. Aerospace Med. 1969;40:1114-1118.

22. Olson RM, Krutz RW Jr, Dixon GA, Smead KW. An evaluation of precordial ultrasonic monitoring to avoid bends at altitude. Aviat. Space Environ. Med. 1988;59:635-9.

23. Waligora JM, Horrigan DJ, Conkin J. The effect of extended oxygen prebreathing on altitude decompression sickness and venous gas bubbles. Aviat. Space Environ. Med. 1987;58:A110-112.

24. Webb JP, Ryder HW, Engel GL, Romano J, Blankenhorn MA, Ferris EB. The effect on susceptibility to decompression sickness of preflight oxygen inhalation at rest as compared to oxygen inhalation during strenuous exercise. Comm. Aviat. Med. Report #134. 1943;6pp.

25. Webb JT, Krutz RW Jr, Dixon GA. An annotated bibliography of hypobaric decompression research conducted at the Crew Technoloby Division, USAF School of Aerospace Medicine, Brooks AFB, Texas from 1983 to 1988. USAFSAM Technical Paper 88-10. 1988;22pp.

26. Whiteley AH, McElroy WD, Warren GH, Harvey EN. Bubble formation in animals. V. Denitrogenation. J. Cell. Comp. Physiol. 1944;24:257-71.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0183

1a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) USAFSAM-JA-89-21	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION KRUG International Technology Services Division 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION USAF School of Aerospace Medicine
6c ADDRESS (City, State, and ZIP Code) P.O. Box 790644 San Antonio, TX 78279-0644	7b ADDRESS (City, State, and ZIP Code) Human Systems Division (AFSC) Brooks AFB, TX 78235-5301
8a NAME OF FUNDING/SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-85-C-4503
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO 62202F; PROJECT NO. 7930; TASK NO 17; WORK UNIT ACCESSION NO 05

11 TITLE (Include Security Classification)
Potential for Reduction of Decompression Sickness by Prebreathing with 100% Oxygen while Exercising: A Review

12 PERSONAL AUTHOR(S)
Webb, James T.; Dixon, Gene A.; Wiegman, Janet F.

13a. TYPE OF REPORT	13b TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM ____ TO ____		

16 SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
06	04	
06	10	

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Decompression Sickness, Hypobaric, Ultrasound, Doppler, Hematologic, Review, Exercise, Prebreathe, Denitrogenation

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Exercise performed for at least 30 min while prebreathing 100% oxygen prior to decompression has been reported to increase efficiency of denitrogenation by 100-500%. The incidence of decompression sickness following such a prebreathe was decreased by 50% compared to resting prebreathe. If prebreathing with exercise is to have an operational application, it must be brief, it must significantly reduce standard prebreathing times, it must not create excess fatigue, and it must use exercise equipment compatible with aerospace operations. This article provides background and recommends parameters for a test to determine the operational feasibility of prebreathing with exercise.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Larry J. Meeker, B.S.	22b TELEPHONE (Include Area Code) (512) 536-3811 / 22c. OFFICE SYMBOL USAFSAM/VNS

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED